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EFFECT OF CO_2 LASER ON SOME PROPERTIES OF $NI_{46}TI_{50}CU_4$ SHAPE MEMORY ALLOY

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ABSTRACT

The microstructure, mechanical and corrosion properties of Nickel-Titanium-Copper shape memory alloy were studied in this paper. The Ni_{46}-Ti_{50}-Cu_4alloy was prepared using the powder metallurgy technique, and then mixed and cold pressed at (600,700 and 800) MPa to arrangement cylindrical specimens of (11mm diameter×16.5mm length).After pressed the samples had sufficient green strength for handling. The specimens were consequently sintered at (850,900 and 950) ˚C for five hours in an electric vacuum furnace. The optimum compacting pressure and sintering temperature were identified using Minitab program. Samples prepared under the optimum process conditions were then irradiated using a continuous CO_2 laser at5w, 10w and15w. Multiple investigations were conducted on the alloys including shape memory effect, microstructure, scanning electron microscopy (SEM) and hardness. The results indicate that increase hardness after Laser processing

KEYWORDS: CO2laser, NiTi, Shape Memory Alloy & Powder Metallurgy

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Original Article

INTRODUCTION

Shape-memory alloys have extensive numerous applications in different technological fields given their excellent properties. The shape-memory effect (SME), i.e., the recovery of a "memorized" shape after deformation, is attributed to a thermo-elastic martensitic transformation. Equiatomic NiTi shape-memory alloy has potential novel biomedical applications given its super-elasticity, shape-memory properties, and biocompatibility [1- 5]. Nitinol is the most common type of shape-memory alloy. It is based on Ni and Ti, the most popularly used metals in shape-memory alloys with commercial applications given their good mechanical properties and SME [6]. Shape-memory alloys are subjected to various surface-treatment techniques and protocols for improving their corrosion resistance and increasing their available bioactive surfaces. These methods include mechanical and electrochemical treatments, chemical etching, heat treatments, conventional and plasma-ion immersion–implantation, laser and electron-beam irradiation [7-10]. Laser-based surface modification techniques are the most commonly used surface-engineering tools because they enable rapid heating and melting that subsequently extend the solid solution, refine microstructures, and homogenize alloy composition to yield products with excellent metallurgical interfaces [11-15]. Laser surface treatment is a viable means for modifying the surface properties of materials [16-20] because of its flexibility, high precision, and intense beam power [20-22]. The electromagnetic radiation of a laser beam is absorbed within the surface layer of metals. Thus, laser energy can be deposited exactly at the point where it is needed [23-25]. the main object of this work is to Optimize the shape memory

effect of Ni-Ti-Cu alloy using Minitab program, then manufacturing the optimum sample and testing it to verify the obtained result and Study the effect of different laser power on the corrosion rate for Ni-Ti-Cu alloy also its effect on the surface and structural properties.

Experimental Work

The arrangement of the powders was the principal step in this work. NiTiCu powders were directly used to prepare the SMA samples. NiTiCu powders were foreign made from (Sky Spring Nano materials, Inc., USA) with high purity (>99%) and molecular estimates of 44 microns (325 mesh). The PM framework was used to produce the samples Powder metallurgy system was utilized to prepare the samples, close net shape items with better properties could be developed utilizing this technique.

The powder mixture, which included 50% Ti, 46% Ni, and 4% Cu, were placed into a glass tube holder, the powders were mixed by utilizing an electrical parallel mixer at a rotational speed of 70 rpm for 2 hours in accordance with reference [26].

The powder mixture was compacted using a press device under pressures of 600, 700, and 800 MPa to shape the mixture into cylinders that measured 11 mm in diameter and 16.5 mm in length. The compaction displacement rate of the press machine was 1 mm/min.

Table 1: Structure and Measurements of Samples with Compacting Pressure and Sintering Temperature

Alloy Composition	TI_{50}	Ni_{46}	Cu_4
Compacting pressure(mpa)	600	700	800
Sintering Temperature(^{0}c)	850	900	950
Samples Dimensions(mm)	11 mm diameter and 16.5mm length		

The green samples were sintered in an electric tube furnace supplied with a quartz tube and a vacuum apparatus, at 850 °C, 900 °C, and 950 °C for 5 hours in accordance with reference [27], followed by slow cooling in the furnace.

The Shape memory effect test was conducted by compressing the samples to 0.06% of their original lengths at a displacement rate of 1 mm/min and then heating them at 110 °C for 5 min. The compressed samples were then allowed to slowly cool in open air. SME (shape effect %) was calculated by applying the following equation:

$$\text{Shape Effect (\%)} = \frac{L2-L1}{L0-L1} \times 100 \;\ldots\ldots\ldots\ldots \qquad (1)$$

[27]Where:

L_0: the original sample length

L_1: sample length after compaction by 0.06%

L_2: recovered length after heating.

After determining the conditions (i.e., compacting pressure and sintering temperature) from the Minitab program that can provide the ideal SME, the specimens were prepared by utilizing PM technique. The shape memory effect test was conducted to make sure of the obtained result value.

Laser surface heating, i.e., rapid solidification process (RSP), is a laser surface modification technique for improving corrosion resistance. The laser used in the present work is a continuous CO_2 laser with wave length10.6 µm and laser powers of 5w, 10w, 15w. In this work, the distance between the laser and the sample is 50 cm. The surface temperature of the sample must not exceed 300 C to avoid thermal damage [10]. Thus, Equation (2) was used to determine the amount of laser energy that exerts the optimum surface effect without causing thermal damage.

$$T(z,t) = \frac{2H}{K}[\sqrt{\mathrm{k}}\,t\ \mathrm{ierfc}(\frac{Z}{2\sqrt{\mathrm{k}t}})] \quad (2)$$

$$ierfc\ (0) = \frac{1}{\sqrt{\pi}}\ldots \quad (3)$$

$$H = \frac{P(1-R)}{A} \quad (4)$$

t: (5 minutes)

H: Surface power density

K: Thermal conductivity (0.1w/cm. ºC for NiTi alloy)

ƙ: Thermal diffusivity ($\frac{K}{\rho C}$ m^2 /s)

C:Specific heat capacity (0.322 J/g. ºC for NiTi alloy)

ρ: Material density (6.7 g/cm^3 for NiTi Cu alloy).

R: Reflectivity = 0.65

P: power

The microstructures of the treated and untreated samples were examined by utilizing an optical microscope connected to a computer.

The surface morphology of Ni_{46}–Ti_{50}–Cu_4 alloy was inspected by utilizing a scanning electron microscope before laser and after laser processing

The surface hardness of the specimens was measured using a Vickers small-scale hardness test device. Hardness was estimated thrice in locations along the surface of each sample, and the average of the three readings was used to obtain hardness.

Corrosion was facilitated using Hank Solution. The pH was measured and set to 7.4, which approximated human body pH.

RESULTS AND DISCUSSIONS

The shape memory effect percent (shape recovery)shown inthe table (2) was measured at variable compacting pressure and sintering temperature. The results showed that the shape effect increased with increasing compacting pressure at low sintering temperatures. The best shape recovery was 83.4% at a compacting pressure of 800 MPa and a sintering temperature of 850 °C.

Table 2: Shape Memory Effect Result

Compacting pressure (MPa)	**600**	**700**	**800**	**600**	**700**	**800**	**600**	**700**	**800**
Sintering tempereture (°C)	850	900	950	850	900	950	850	900	950
Shape effect (%)	74.37	62.8	60.04	78.21	65.77	63.14	83.45	73.46	70.87

A regression equation was used to estimate the temperature and pressure that provided the maximum SME value. The following result was obtained:

Shape effect (%) = 160 + 0.0510 p_0.140 T (5).

If the sintering temperature 750 °C is considered, then the compacting pressure 882MPa was obtained.

Shape effect (%) = 99.98with Regression value of 90.7%.

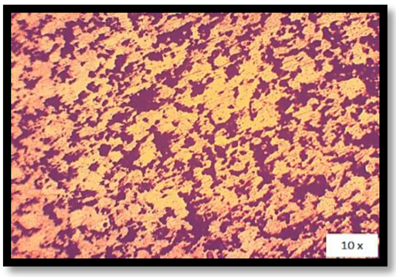
This specimen was manufactured using powder metallurgy method and subjected to the laser irradiation.

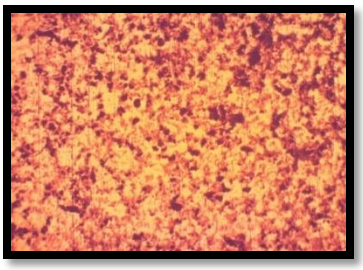
Theoretical calculations performed using Equation (4) showed that laser energy must not exceed 19 watts to exert the maximum surface effect on the specimens without causing thermal damage.

The experimental results showed that sample surfaces were damaged when irradiated with the power of laser 15 watt; the reason for non-coincidences between theoretical and experimental calculations due to surface morphology of the sample especially roughness of the surface. part of the incident beam is reflected.

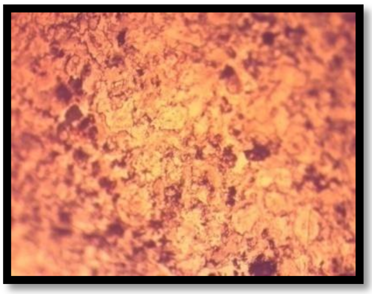
The grain and grain boundary of all the tested samples appear clear in this test, thereby indicating the success of the manufacturing process.

The microstructure after irradiation with different laser powers (5, 10, 15 watts), as shown in Figures (1), the grain sizes of the samples were improved and the grain boundaries were growing because of the considerable amount of energy at the grain boundary. Irradiation with a laser power of 10w yielded the best results because the growth of the grain boundary was increased.

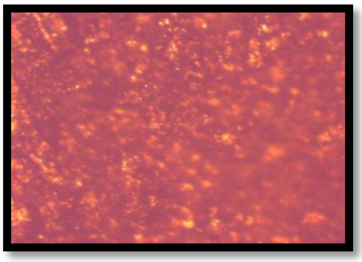




(a) **(b)**



(c)



(d)

Figure 1: Microstructure of the Specimens
(a) Before Laser (b) After Irradiation with Laser Power 5w
(c) After Power 10w (d) After Power 15w.

Scanning Electron Microscope offers additional details about the alloy microstructure, as shown in the test image results. The samples with large grains, the formation of the grain boundary, and the appearance of pores before laser irradiation are shown in Figure (2).

The SEM images of the microstructures of the samples after irradiation with different laser powers are shown in Figures (3 a, b,c), which indicates that porosity decreased after laser irradiation. The irradiated region was uniform and homogeneous. These characteristics increased hardness.

After comparing the different laser powers from optical microscopy and SEM, irradiation with a laser energy of 10w was determined to obtain the best microstructural feature.

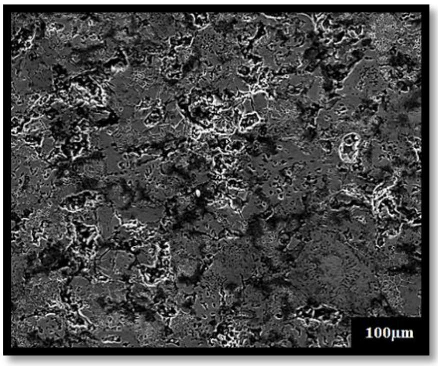
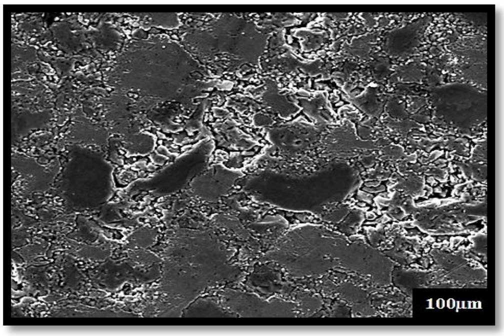
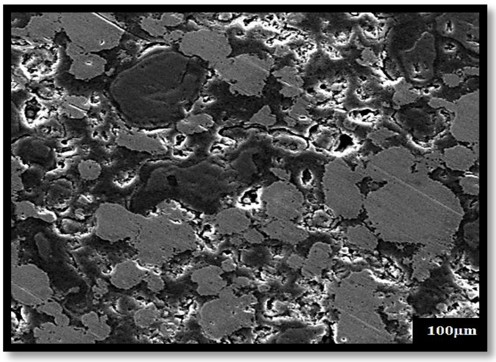


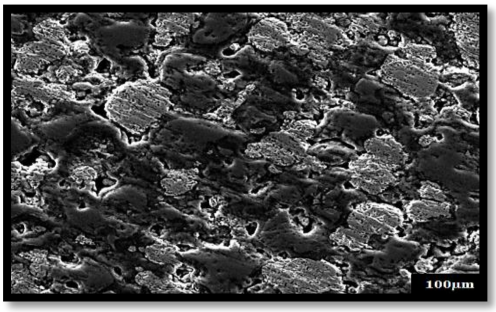
Figure 2: Scanning Electron Microscope of the as Received Sample



(a)



(b)



(c)

Figure 3: Scanning Electron Microscope of Samples After Irradiation with Different Laser Powers (a) 5w (b) 10w (c) 15w.

The microhardness test results showed that the samples before laser equal to 199 HV, after laser power 5w equal to 240 HV, after laser power 10 w equal to 380.4 HV and after irradiation sample with laser power 15w the surface was damaged and hardness value degrees to 100HV.

Open circuit potential (OCP)- time measurements were conducted on all the optimum specimens before and after irradiation with different laser powers. The outcomes provide respectable information about the initial polarization curves. The polarization examinations were directed using hanks solution at 37±1 °C. The results showed that the corrosion rate decreased with increasing laser power because of the decrease in pore sizes, which reduced the surface area subjected to hank solution and led to a decrease in the measured corrosion rate.

Figure (4) presents the electrochemical curve of the NiTiCu sample before laser irradiation. The corrosion rate of the asreceived sample is 44.7 mph. After irradiating the samples with different laser powers (5, 10watt), as shown in Figure

(5), the corrosion rate decreased to 18 mph at 5watt and 8.3 mph at 10 watts. These results indicated that the corrosion potential was decreased after laser processing.

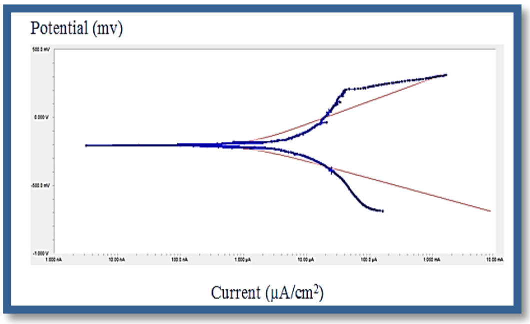
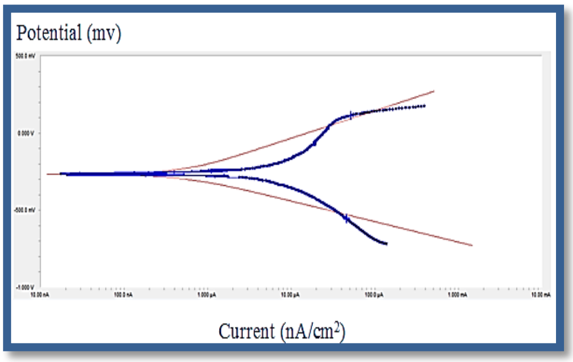
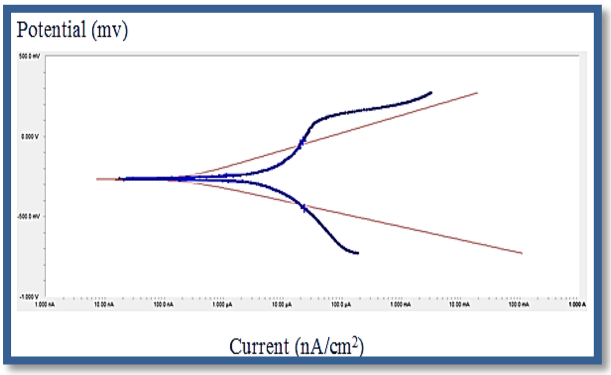


Figure 4: Current Density (Amp/Cm^2) vs. Potential (V) for Sample Before Irradiated with Laser



(a)



(b)

Figure 5: Current Density (Amp/Cm^2) vs. Potential (V) for Sample After Irradiated with Laser Power (a) 5 watt (b) 10 watt.

CONCLUSIONS

- The results of the SME test revealed that the best recovery was 83.4% under the highest pressure of 800 MPa and sintering temperature of 850 °C.
- Irradiation at 10w and wavelength of 10.6µm for five minutes enhanced the hardness of Ni-Ti-Cu samples.
- The lowest value of the corrosion rate was obtained after laser power 10watt, which corresponds to the structural

and physical properties

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